INTERPRETIVE AGENTS: A HEATBUG REFERENCE SIMULATION

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ABSTRACT

Interpretive heatbugs (IHB) is a reference application designed as the first implementation of the interpretive agents (IA) research program. As described in previous papers, the IA initiative identifies three mechanisms (prototype reasoning, situation definition, and orientation accounting) to create an interpretive architecture that supports agents whose actions are oriented by meaning.

The reference application uses the familiar heatbugs environment, where bugs require a temperate zone and flee from settings that are uncomfortably hot or cold. Because each bug emits a small amount of heat, congregations of bugs initially create needed warmth, but then overcrowding creates excessive heat, with the feedback creating unstable churning patterns.

To this dynamic of temperature fluctuation driving bug movements, IHB adds the capability of bugs to assist or undercut each other and ethnic and religious identities that mediate the decisions to help or hinder. IHB intends to provide an exemplar for a wide variety of cultural interactions, including, not only genocide and ethnic cleansing but also diversifying markets and constructive interdependencies.

OVERVIEW

Agent simulation is a methodology that has been an important innovation in the social sciences. Through the device of distributed, endogenously motivated software agents, a range of social processes have been simulated in interesting ways. The variety of ways in which microinteractions produce familiar large-scale effects has been a source of insight and held promise for future research.

If the insight arising from simple models has been the fruit of embryonic agent simulation, it also constitutes a ceiling. The first generation of agent simulation has been largely characterized by simplicity in rules, agents, relationships, motivational structures, and resulting processes. The challenge for modelers is to retain the clarity of simple models while, at the same time, extending them in order to more fully capture the fluidity of social relationships and processes.

Many artificial intelligence research programs have sought to computationally effectively emulate natural intelligence in its fullness. The interpretive agent (IA) research program is based

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on the premise that it is possible to capture the nonlinearity of interactive dynamics arising from the processes of social construction and interpretation without first establishing strong forms of artificial intelligence (Sallach 2000, 2003). More specifically, interpretive agents are context-sensitive and meaning-oriented, registering the flow events and shifting their goals, intentions, and actions accordingly (Mellarkod and Sallach 2005a; Sallach and Mellarkod 2004, 2005).

The IA architecture is based on three interleaved mechanisms: prototype reasoning, situation definition, and orientation accounting. Prototypes provide a calibrated implementation of bounded rationality. The process by which participants define situations generates a contextual framework and provides a focus of activity. Participants and relevant nonparticipants maintain and, to some extent, share orientations toward a significant group, object, symbol, etc. Accordingly, as communications and actions are generated, they must take such constraints into account and adjust accordingly.

Ultimately, all interpretive mechanisms in the IA research program are based on geometrical models of meaning (Gardenfors 1999; Widdows 2004). Taken broadly, the latter attributes meanings on the basis of their proximity to a reference point in a conceptual or semantic space. Reference points are defined relative to exemplary and/or idealized concepts, where both serve as reference points. Prototype reasoning, as implemented in this reference application reported here, utilizes reference points based on empirical exemplars.[1]

A REFERENCE APPLICATION

The “heatbug” application has played a significant role in the history and emergence of agent simulation. It provides a simple, controlled example that has served to illustrate basic design and techniques. The goal of the present paper will motivate an analogous reference application for interpretive agent simulation.

A reference application is one that defines and implements generic mechanisms for a specific type of problem domain. These implemented mechanisms provide an exemplar for developers who want to construct an application of that type. Specifically, developers can take the generic mechanisms of the reference application and customize them to address the requirements of the detailed structures and dynamics of a particular scientific, institutional, or business area.

The application “interpretive heatbugs” (IHB) is conceived as a reference application for how interpretive agents can be designed and developed in a relatively simple setting; it provides a way to illustrate the concepts and mechanisms and acts as a modest example of how they may be implemented. The described reference application is implemented in the J mathematical programming language (Thomson 2001; Peele 2005).

The present discussion summarizes how the IA mechanisms are designed and the assumptions on which the application is based. The focus is on what aspects of meaning orientation in social settings are used to motivate the design and the way that this reference application is intended to serve as a bridge to social simulation models and applications. More

[1] The mechanisms for both types of reference points are actually similar, attributing meaning on the basis of proximity.

detailed design considerations, and the implementation of the mechanisms and their interaction, are discussed in a parallel paper (Mellarkod and Sallach 2005).

Interpretive heatbugs inhabit a setting comparable to the original heatbug setting. Agents seek a location with a comfortable temperature within a “heatspace,” experiencing discomfort from excesses of heat and cold. Each bug emits a small amount of heat, which, in aggregate, contributes to temperature differences and evolution. interpretative heatbugs are assigned regions of comfort, discomfort, and extreme discomfort that are unique to them. In the baseline implementation reported here, they assume other bugs share equivalent zone sensitivities. Interpretive heatbugs have a basic energy metabolism that is more rapidly depleted in areas of higher discomfort. If their energy drops below zero, they can only undertake movement on alternate ticks. In later versions, we may introduce bug demographics; in this case, bugs without energy resources will die.

In addition to movement, which is governed by discomfort levels, bugs have three additional capabilities and proclivities: asking for energy, giving energy, and shoving their way into more comfortable locations. In the baseline model, the three actions are defined by exogenous rules, except that many of the governing rules fire relative to conceptual prototypes of how *#similar, #nice,* or *#tough* pertinent bugs are,[2] where the latter are defined in Table 1.

TABLE 1 Pertinent Bugs in IHB Rules

Activity	Pertinent Bugs
Asking for energy	Bugs that are potential donors
Giving energy	Bugs requesting energy
Shoving	Bugs attempting to enter the same cell

The *#similar*, *#nice*, and *#tough* prototypes[3] are defined by the idiosyncratic training and experience of the individual bug; therefore, each has a unique interpretation of the concept. However, all such attributions are mediated through two geocultural forms of social structure: ethnicity and religion. Ethnicity becomes a locus of identity and in/out group dynamics. Religious identification serves as a source of tighter or looser value commitment. Religion also has more finely grained distinctions that are known to members and to those who know them well but not to casual outsiders. All such complexities, including behavior that can be observed in particular circumstances, define distinctions that can be used by the reference point reasoning of the bug.

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2 By convention, words that stand for conceptual prototypes are marked by a pound (#) sign. The hash mark is meant to suggest the radial structure of the prototype it represents. For both the designers and the bugs, a conceptual prototype is a *region* within the space of experience and thus semantic space as well. With the multiple dimensions and semantic variety implied by its radial structure, the region cannot be fully or adequately conveyed by a single label.

3 The particular conceptual prototypes used in the baseline design are designed to illustrate the operation of conceptual and computational mechanisms, not to express an articulated social or psychological theory.

IHB is a reference application and is thus meant to provide an example for richer social models. Additional kinds of structure (e.g., age, gender, status, wealth) can be added and taken into account by prototype inference. Available actions can become more calibrated, more closely aligned with social and historical issues, and, ultimately, be given prototypical form. In this way, IHB is designed to provide a catalyst for a new generation of social simulation models.

Modern history is replete with examples of genocide, ethnic cleansing, human rights violations, and movements for civil and/or minority rights in which ethnicity and religion have served as interpretive queues for mass behavior. IHB is designed to facilitate the construction of models that locate such historical events within interpretive social processes.

ABSTRACT SOCIAL STRUCTURE

Social structure is a historically pervasive formation that envelopes and shapes all social action. Its effects are subtle and complex, varying in form and effect, yet there are relatively simple commonalties that underlie its diverse manifestations. A synthetic model of social structure will undertake to integrate simplicity and complexity within a formal model. The complexity of the model will allow expression of the texture of empirical social life; its simplicity will facilitate inference about structural dynamics.

Social structure can be modeled at multiple levels. It can be defined abstractly, so that *diverse historical structures* (e.g., serfdom, patrimonialism, slavery) *can be compared* on pertinent criteria. An advantage of developing an abstract definition of social structure is that social structures *before and after a transformation can be explored*. Second, the social structure of any given historical conjuncture can be *framed in historical context* or *articulated in greater depth*, as illustrated by numerous stratification examples (e.g., Frazier 1957; Warner 1960; Dumont 1970; Zeitlin and Ratcliff 1988).

Development of an abstract concept of social structure can contribute to social modeling. Specifically, to the extent that historically unique structures can be understood as variations on an abstract concept and articulated accordingly, the ability to apply a common model to highly diverse social phenomena enhances our ability to model them comparatively.[4] One purpose of the IA research program is to investigate how microinteraction can produce large-scale spatially distributed structures.

Regarding stratification patterns, perhaps no contemporary theorist has articulated a model as synthetic across levels as has Randall Collins. Within an emphasis on theoretical coherence and cumulation, Collins's contributions can be seen to lie in three primary areas: (1) the location of stratification processes within a broader social context, including the significance of interaction rituals (1987); (2) the recognition and articulation of the role of emotion in stratification dynamics (1981,1990); and (3) a recurrent focus on the integration of macro and micro processes (1981, 1988, 2000).

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4 Ultimately, abstract models can be used to *generate* distinct patterns, including forms of social structure that may not have historically existed but, given a theoretical concept of how social structure is composed, are possible.

Macro Context

Whether the conception is abstract or concrete, social structure is located within an enveloping context. Collins (1988, pp. 395–397) describes three dimensions of this macro milieu as space, time, and number. These three dimensions may be considered as an informational context within which abstract social structure can be defined. While space and time may reasonably be indicated as points or extents, number is inherently more complex. Collins (1988, p. 394) describes it as the "number of people or situations involved," but, as a dimension of social structure, number must be more fully described.[5]

Space is the dimension along which geographical dispersion occurs. Dispersion may take, inter alia, the form of genetic inheritance, migration, contagion, diffusion, or imitation. The spatial dimension includes race and ethnicity and also multiple layers of cultural forms. Regardless of the means of dispersion, civilization, nation, language, religion, and various cultural traditions, rituals, and practices all spread geographically. They may be regarded as layers of social differentiation, branching through space-time (cf., Cavalli-Sforza 2000). The integration of geocultural spatial layers is an essential step toward representing the complexity of social structure in coherent ways.

The IHB reference application implements a simple form of geocultural social structure in which a notional interaction among heatbugs manifesting diverse ethnic and religious patterns is modeled. Empirically, the relationship between these two geocultural structures can be fairly complex, as suggested by Figure 1, which uses census data to show the interaction between ethnicity and religion in the United Kingdom.

Geocultural layers can converge as well as diverge. Marriage and progeny can unite two ethnic groups. Children can be taught to be fluent in a second language (Laitin 1994). An innovative religious movement may borrow from and emulate a competing religious tradition. Accordingly, geocultural evolution can be best represented as a network with the potential for both divergence and convergence (rather than as a hierarchical structure).

Although not currently represented in the IHB reference application, for the sake of completeness, the other two dimensions of abstract social structure are briefly summarized as well. Time is the dimension in which social activity occurs. While the content of human activity is ceaselessly creative (Pareto 1980; Joas 1996), forms of activity recur as well. Such recurrence is recognized and functionally codified in the division of labor (Durkheim 1933; Luhmann 1982; Turner 1995; Mark 1998). One of the most fundamental divisions creates institutions that become semiautonomous from the larger community: the state in prehistory, religion in antiquity, and the economy in modernity. Each emergent institution is further functionally differentiated in historically and culturally specific ways, forming a complex network. In most cultures, there are also age- and gender-based aspects of the division of labor, yielding what might be called a biofunctional form of differentiation.

The third contextual dimension of social structure is based on the accumulation of resources. The types of resources accumulated in history have been highly diverse. Classically,

[5] Informally, for the purpose of the present discussion, "number" is applied to the resources that partially constitute stratification processes.

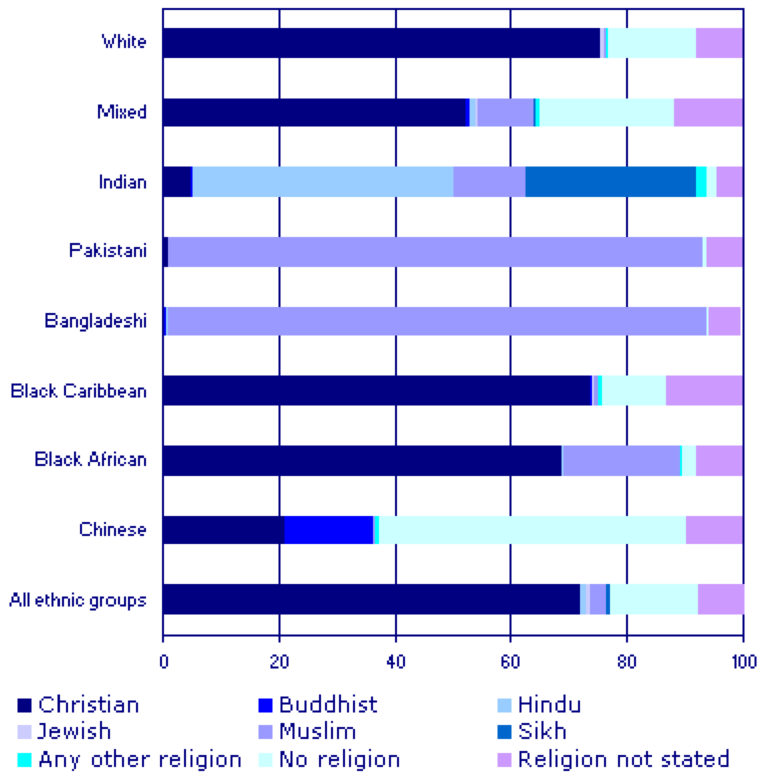

FIGURE 1 Ethnicity and religion in the United Kingdom

Weber (1968) distinguishes the accumulation of economic, social, and political resources in the form of class, status, and party. Such a high-level classification, however, does not begin to suggest the range of resource types that have been accumulated, including social deference, cattle, land, slaves, sexual access, political office and influence, precious metals, symbolic certificates of business ownership, and electronic currencies (Collins 1976, 1987).[6]

Accumulation is inherently hierarchical. In specific historical settings, each resource has formed a dimension of the situated stratification system in which parallel systems of accumulation intertwine in structured ways. It is evident that in modern society, there are numerous accumulation hierarchies, manifesting subtle and dynamic interactions that together form a complex system of stratification (Blau 1977; Zelizer 1994). Complexities, however, are present in stratification systems of simpler societies as well. Investigations reveal that such historically specific complexities should not be underestimated (Lenski 1966; Dumont 1970; Dirks 2001).

Viewed in the broadest comparative context, dispersion in space, functionality in time, and accumulation of resources together produce a diffuse coordinate system that is vast and complex but never actually encountered in any historical setting (Figure 2). On the

6 A stratification system also shapes the cognitive framework through which the world is comprehended (cf., Sallach 1974; Smith 1987; Sewell 1992).

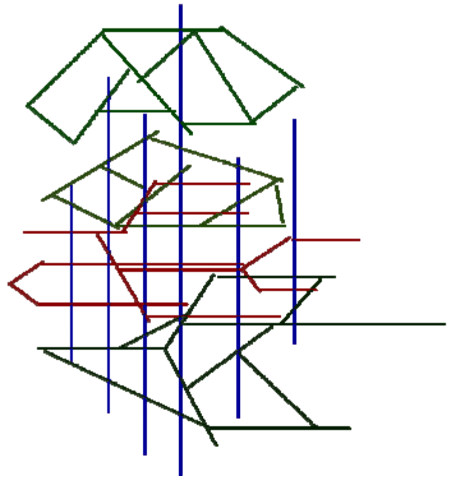

FIGURE 2 Three abstract dimensions of social structure

contrary, a coordinate system defined by macrocontext is a product of scientific theory. Defined in abstraction, *it provides a means of comparing and generalizing across cultures and time periods*.

Abstract social structure defines an analytical context in which historical social structures arise, evolve, and sometimes disintegrate. Situated structures, on the other hand, define a locus in which microinteraction draws upon and shapes the macro patterns of structure (Smith 1987; Scheff 1990; Sewell 1992; Collins 2000).

BUG ETHNICITY AND RELIGION

The reference application considered here implements two forms of geocultural structure: ethnicity and religion. The purpose is to provide forms of social structure the attribution of which shapes interactions and also serves as a generic model for applications that require richer forms of social interaction.

The number and relative size of multiple ethnicities are exogenously defined, and, subject to those constraints, bugs are randomly assigned an ethnic identity. Each ethnicity also has a defined value on a "clusivity" dimension, which varies from +1 (highest inclusivity) to –1 (highest exclusivity). The clusivity value determines the center of a range from which individual clusivity is randomly assigned.

Similarly, the number and relative size of multiple religions are also exogenously defined and randomly assigned. However, religions differ from ethnicities in two ways. First, rather than clusivity, religious identity is mediated by multiple (currently two) forms of religiosity, which determines the extent of various religious influences on the individual. Each religion is randomly assigned a value on a nice/tough dimension,[7] and religiosity determines how closely the (religious) group intensity determines individual aggressiveness and generosity values.

A second difference concerns the fact that religions can have a subreligion as well. Subreligions have distinct (and controlling) nice/tough values. However, members of other religions cannot perceive subreligion distinctiveness until or unless they have been neighbors with members of that subreligion for a specified period of time. This perceptual limitation tends to blur the visible relationship between religious identity and action; thus, it contributes to the diverse concepts of religions that compete in the larger population.

Bug action rules (that govern asking, giving, and shoving) are also mediated by ethnic and religious identities and perceptions. Rules are not the only way that prototype concepts might be translated into actions, but, in the reference application, they illustrate how casual observation, and the prototypes formed thereby, can contribute to the calibration of agent concepts and responses (Figure 3).

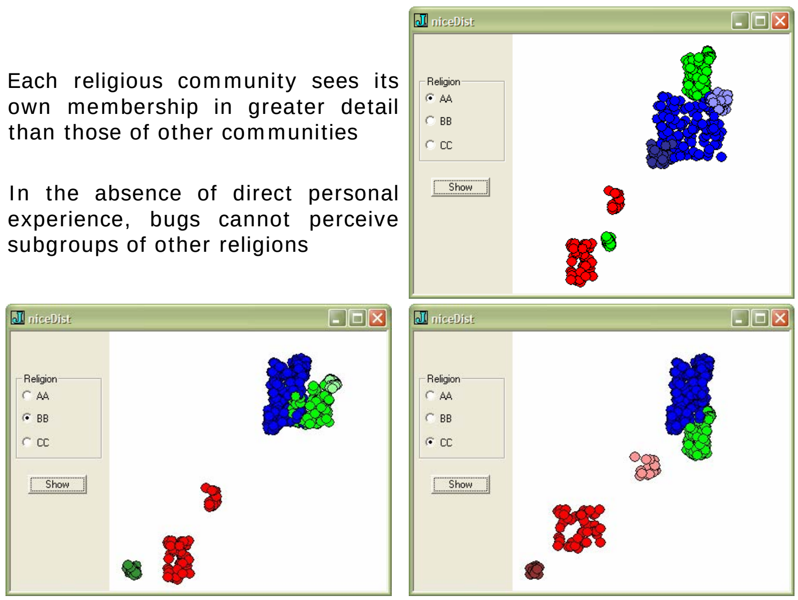

FIGURE 3 Fractal visibility

PROTOTYPE REASONING

Since antiquity, it has been assumed that the concepts employed by the human mind can be described in Aristotelian form; that is, that objects are organized by *genus* (class) coupled with *differentia* (distinguishing characteristics sufficient to produce an unambiguous definition). A bird, for example, is sometimes defined as a biped (*genus*) with feathers (*differentia*).

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7 These two values are viewed differently, of course, depending on the perspective of the bug. Nice bugs tend to view tough bugs as mean, while tough bugs are inclined to view nice bugs as weak.

In the final quarter of the twentieth century, however, cognitive science research called the Aristotelian model into question. Seminal and well-replicated studies reveal that human conceptual structures are organized in terms of family resemblances (Rosch 1978; Heit 1997). A prototype or exemplar defines a reference point, relative to which other examples are classified in terms of their similarity, along radial dimensions of difference. Stated differently, prototypes may be regarded as a focal object or event that serves as the reference point for objects or events that are more or less similar.

An entire concept referenced by its prototype is the subject of proximity-based reasoning. Rosch (1983) refers to the overall cognitive process as reference point reasoning. The latter incorporates the typicality of any given instance relative to the radial structure of the concept as a whole. In a given situation, various prototypes may be comparatively assessed with regard to which is most appropriate for understanding the entity and/or situation at hand. When considered in conjunction with the Miller (1956) constant, an early formulation of bounded rationality constraints, the latter defines a (slightly variable) constraint that controls the number of prototypes considered in such comparisons.

In the reference application reported on here, interpretive heatbugs note the behavior of their neighbors and, on the basis of their observations, including the neighbors' ethnic and religious markers, construct *#nice, #similar,* and derivative prototypes that can then be used in applying their distinctive rules to new situations.

GENERATING SOCIAL COMPLEXITY

As Simon (1996, page 53) hypothesized, "The apparent complexity of [human] behavior over time is largely the reflection of the complexity of the environment in which we find ourselves." This insight is both a challenge and potential source of reassurance about the potential for the emergence of a truly scientific sociology. To the extent that modest but social skills enable adaptation (as well as mere coping) in strikingly diverse but always complex environments, our modeling task may be more tractable than we sometimes fear.

There are numerous sources of social complexity, and they interact in ceaseless flux. In expansive contexts, rationality bounded in space and time assures that generalizations are idiosyncratic, shared in only limited ways, and constantly evolving. Frameworks enabling coordination must be socially *achieved* by using relaxed expectations and/or carefully selective imputations of commonality. An emphasis on coordinated action as an *accomplishment* results in a healthy reorientation of social analysis toward shared *capabilities*, and they are what must (remain to) be modeled. The present initiative seeks to forge a reachable exemplar along this path.

Among our preliminary insights along the present path is that extensive and generative initialization is essential for producing the needed complex social setting and its derivatively subtle agents. It is also clear that continued progress in visualization tools is vital to illuminate regions that are important but not directly observable in empirical settings.[8] Chief among such areas is the amorphous field of intentionality. A very fluid attractor system (cf., Juarrero 2000), indeed, will be required to adequately express the interactive dynamics of intentionality.

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[8] Bell (2004) calls them "beables."

CONCLUSION

IHB is a reference application that serves as an initial implementation of the IA research program. The initiative has developed a computational implementation of three social mechanisms (prototype reasoning, situation definition, and orientation accounting) that emulate agents whose actions are *oriented by meaning*.

While this reference application uses the familiar heatbugs environment, where bugs prefer a temperate zone while escaping from settings that are uncomfortably hot or cold, such exogenous constraints serve primarily to establish the dynamic context for interpretive interaction. IHB adds the capability of bugs to help or hinder each other, mediated by modestly complex ethnic and religious identities that shape their situated responses. Prospectively, IHB provides an exemplar for diverse cultural interactions, including not only genocide and ethnic cleansing but also diversifying markets and civilizational interdependencies.

ACKNOWLEDGMENT

This work is supported by the U.S. Department of Energy, Office of Science, under contract W-31-109-Eng-38.

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